AFGHANISTAN
Firing Artillery Accurately with Air Force Met Support

By First Lieutenant Joshua D. Mitchell

In the summer of 2002, Task Force Panther, 82d Airborne Division, Fort Bragg, North Carolina, received the mission to replace the 101st Airborne (Air Assault) Division in Afghanistan in support of Operation Enduring Freedom. Due to limited airspace and the limited amount of indirect fire assets tasked—a 105-mm battery and two 120-mm mortar platoons for the one FA battalion deploying—the division artillery meteorological (Met) team remained at Fort Bragg. Left without one of the five requirements for accurate, predicted fire, Charlie Battery, 1st Battalion, 319th Airborne Field Artillery Regiment (C/1-319 AFAR) developed techniques to accurately account for the extreme climate of the combat theater.

Before the battery arrived, A/1-319 AFAR, already in Afghanistan, was reporting range and fuze setting errors during live fire missions while using 120-mm mortars. These errors largely were due to the high temperatures and reduced air density of the Southwest Asian country. C Battery began to see similar firing errors when it calibrated in the desert south of Kandahar. The battalion's Q-36 radar at Kandahar repeatedly reported rounds impacting over the target while the radar was set in the friendly mode.

Due solely to weather conditions, the fire direction center (FDC) faced nearly 500 meters in range errors. With initial assistance from the Air Force's Bagram weather team, we developed procedures to negate these errors by using the Air Force's Interactive Gridded Analysis and Display System (IGRADS).

IGRADS is web-based software that generates 24-hour forecasts of weather conditions up to 50,000 feet above the surface for any given latitude or longitude and is accessed through secure internet protocol relay (SIPR) accounts. IGRADS outputs the data in the format of altitude in feet above ground level (AGL), pressure in millibars, temperature in Celsius, density in grams per cubic centimeter, absolute humidity in grams per cubic meter, wind speed in meters per second and wind direction in degrees. The information can be interpolated and converted into a computer Met message; then with the weighting factors found in *FM 6-16, Tables for Artillery Meteorology (Electronic) Ballistic Type 3 and Computer Messages*, it can be converted to a ballistic Met message for mortars.

Quantifying the Problem. Although accounting for Met may make little difference at installations where the weather parallels standard conditions much of the year (such as Fort Bragg), the lack of Met was a serious deficiency in the summer heat and high altitudes of Afghanistan. Low air density, a function of high temperatures and low pressures, reduces the drag of a projectile and, therefore, causes positive range errors.

Heightened temperatures also affect the drag of a round because of their effects on the compression waves that form in front of and behind the projectile. This drag effect is not linear; but for most M119A2 firing data, an increase in temperature corresponds to an increase in achieved range. High desert temperatures combined with high altitudes, therefore, can cause significant deviations from standard.

The Army already has had this problem in Southwest Asia where extreme temperatures and low density caused range corrections of up to 4,700 meters *(FM 6-15 Tactics, Techniques, and Procedures for Field Artillery Meteorology, Page 3-13)*.

Standard Met (Sea Level)					Bagram (1456 Meters MSL)		
Zone No.	Midpoint Height	Pressure (mb)	Temperature (°K)	Density (gm/m³)	Pressure (mb)	Temperature (°K)	Density (gm/m³)
00	0	1013	288.2	1225.0	848	299.2	986.1
01	100	1001	287.5	1213.3	839	298.5	985.8
02	350	0972	285.9	1184.4	815	296.9	977.6
03	750	0926	283.3	1139.2	778	293.8	922.1
04	1250	0872	280.0	1084.6	734	289.8	882.5
05	1750	0820	276.8	1032.0	692	284.9	844.6
06	2250	0771	273.5		651	281.0	
07	2750	0724	270.3		613	276.1	

Legend:
gm/m³ = Grams per Cubic Meter **K =** Kelvin **mb =** Millibars **MSL =** Mean Sea Level

Figure 1: Standard Met Compared to Bagram Met. The Met was taken at 1200 Zulu on 10 September 2002.

The first Met data the Air Force provided using its IGRADS simulation software showed the disparity between the air density and temperature in our area of operations and those of standard conditions (represented in the battery computer system's standard Met file). See Figure 1. On 10 September, the surface temperature at Bagram that is 1,456 meters above mean sea level (MSL) was 299 degrees Kelvin at 1630 local time. The corresponding temperature in standard Met was 279 degrees Kelvin. This seven percent increase would lead to a 195-meter range error when firing at a distance of 11,000 meters, according to Tabular Firing Table (TFT) 105-AS-4. Additionally, the air density at the surface of the Bagram Met was seven percent lower than the equivalent altitude of standard Met, leading to a 281-meter range error. These errors are even more significant when coupled with the fact that 1-319 AFAR's main mission is to provide close supporting fires to Task Force Panther.

Despite the large differences in temperature and density, pressures only diverged slightly between the Bagram and standard Mets. This similarity is largely due to the fact that Bagram and the location on which standard conditions is based both are about 30 degrees latitude, one of the semi-permanent pressure regions created through the earth's patterns of air circulation.

Accounting for Temperature Changes. Before C/1-319th departed Bagram, the Air Force weather station simulated Met data for Firebase Cobra Strike at Khowst that is at an elevation of 1,140 meters. (See the map in Figure 2.) This Met data gave a good representation of pressures for the firebase, but it was still imperative to account for the changes in temperature that happen within a 24-hour period. The difference between the Khowst Met (taken when the surface temperature was approximately 68 degrees Fahrenheit) and the temperature in the middle of that same day (100 degrees Farenheit) caused a plus-250 meter range error because of temperature's dual effect on drag. It was not possible to track these temperature changes through bi-hourly Met messages, as is the normal procedure. Instead, we had to formulate a new technique.

To isolate temperature changes, pressure was set as being independent of temperature, a decision supported by later analysis of temperature and pressure changes through different 24-hour periods. Due to the complexity of meteorological conditions, no direct relationship between temperature and pressure existed in any of the periods studied.

Analyzing temperature gradients over different periods, we found that surface temperature changes in a given day did not affect temperatures at altitudes beyond 4,000 feet (approximately 1,250 meters) above the surface. Irrelevant of the surface temperature, all temperatures from Line 04 of the computer Met message and above were the same in any 24-hour period. This trend is displayed by the data in Figure 3 on Page 40 from 17 November 2002.

Using this information, we created Met messages for five-degree surface temperature intervals from 55 to 100 degrees Farenheit. We calculated these Met messages by taking the given surface temperature and proportionately reducing it to the temperature at 4,000 feet, based on the temperature gradient of the Air Force Met data. This procedure created 10 Met messages with various surface temperatures but with identical temperatures at 4,000 feet and above (See Figure 4 on Page 40.) The same pressures were used for all 10 Met messages.

Once the Met messages were created, the FDC selected them based on propellant temperature. Because propellant temperatures usually lag behind air tem-

Figure 2: C/1-319 AFAR computed Met data for Bagram, Khowst and Shkin using the Air Force's Interactive Gridded Analysis and Display System (IGRADS).

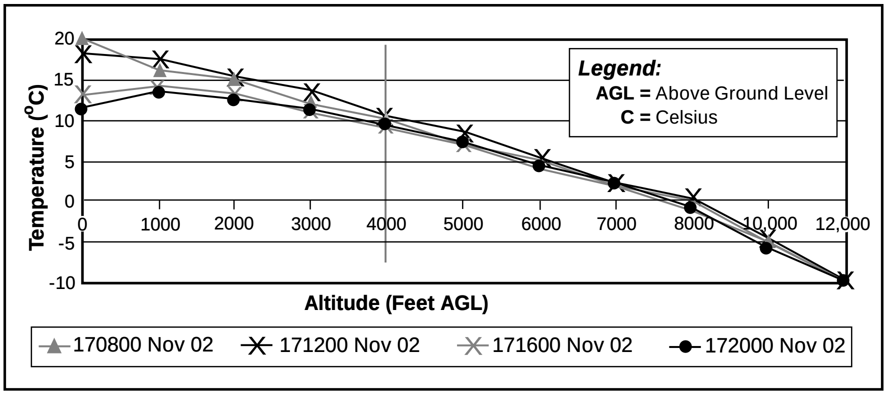

Figure 3: Temperature vs Altitude During a 24-Hour Period

Step 1: Access Data From IGRADS Website.

a. Go to http://weather.offut.af.smil.army.mil/igrads.html using a secure internet protocol relay (SIPR) account.

b. Select Afghanistan—5-kilometer map.

c. Select alphanumeric output.

d. Input latitude and longitude in degrees and minutes.

e. Select the date and time for the Met data —available in one-hour intervals for a 24-hour period.

Step 2: Convert Raw Data into Computer Met.

a. Multiply altitude in feet by 0.3048 to obtain altitude in meters.

b. Add 273.15 to degrees in Celsius to obtain degrees in Kelvin.

c. Based on the age of the Met data, either set wind data to zero or convert direction to mils and speed to knots. If the time of the IGRADS Met data matches within a couple of hours of the time the Met message will be applied, then wind data can be considered fairly reliable. Otherwise, it should be set to zero.

d. Interpolate the data to obtain the weather information at computer Met message midpoint altitudes.

IGRADS Generated Met for 34°57'69°17', 101200 Sep 02			Converted Altitude and Temperature		Final Bagram Met Interpolated at Midpoint Altitudes, Lines 00-04		
Altitude (ft AGL)	Temp (°C)	Pressure (mb)	Altitude (m AGL)	Temp (°K)	Altitude (m AGL)	Temp (°K)	Pressure (mb)
Surface	26	848.28	0	299.2	0	299.2	848
1000	24	819.34	305	297.2	100	298.5	839
2000	22	791.07	610	295.2	350	296.9	815
3000	19	763.56	914	292.2	750	293.8	778
4000	17	736.81	1219	290.2	1250	289.8	734
5000	14	710.70	1524	287.2			

Step 3: Generate Met Messages for Different Surface Temperatures.

a. Using the existing temperature gradient, proportionately converge temperatures at 1,250 meters (or use standard temperature change of –6.5°C per 1,000,-meter increase).

b. Use the same pressures for all Met messages generated.

Bagram Met—Surface Temperature of 79°F			Met for Surface Temperature of 90°F			Met for Surface Temperature of 100°F		
Altitude (m AGL)	Temp (°K)	Pressure (mb)	Altitude (m AGL)	Temp (°K)	Pressure (mb)	Altitude (m AGL)	Temp (°K)	Pressure (mb)
0	299.2	848	0	305.4	848	0	310.9	848
100	298.5	839	100	304.3	839	100	309.4	839
350	296.9	815	350	301.6	815	350	305.7	815
750	293.8	778	750	296.4	778	750	298.7	778
1250	289.8	734	1250	289.8	734	1250	289.8	734

Figure 4: Example of Computation of Computer Met Messages Using IGRADS Data

perature, whether the air is getting warmer or cooler, the FDC would select a Met file offset from the average propellant temperature. For example, the 80-degree Met would be used if propellant temperatures were increasing and averaged around 75 degrees Fahrenheit. In this manner, we accounted for temperature and its effect on the projectile drag.

While the temperature gradient of current Met data is the best representation of the temperatures of the area for a given period, the entire temperature gradient can shift over time. Alternatively, we found that the standard temperature decrease of 6.5 degrees Celsius per 1,000-meter increase in altitude mirrors actual graphs of temperatures for Khowst. (See Figure 5.) Therefore, one should consider using the standard temperature change when no recent Met data is available.

A high-burst registration validated Charlie Battery's procedures a few days after we arrived in Khowst. The registration was conducted 7,005 meters to the northeast with two observers using precision lightweight global positioning system receiver (PLGR) grids. After applying Met and the muzzle velocities for the registered lot, the range correction was only two meters with a fuze setting correction of 0.1. There was still a significant deviation correction, but wind data was not known or applied for the registration.

Further support came during a rocket-assisted projectile (RAP) shoot to the northwest using AH-64 Apache attack helicopters for a laser-adjust mission. At a range of more than 13,300 meters and without a registration, the range correction was merely 33 meters.

Army doctrine warns against using meteorological information more than four hours old or more than 10 kilometers from the midpoint of the trajectory in mountainous terrain. By using IGRADS and accounting for surface temperature changes, Charlie Battery fired accurately with weather information that was up to 30 days old.

Some difficulty arose when the battery conducted missions at altitudes significantly different than the Met station. When the battery flew to Shkin, for example, the firing point altitude of approximately 2,200 meters was nearly double that of Firebase Cobra Strike and Cobra's Met station. Using propellant temperatures as a basis for selecting the Met file to use would not work

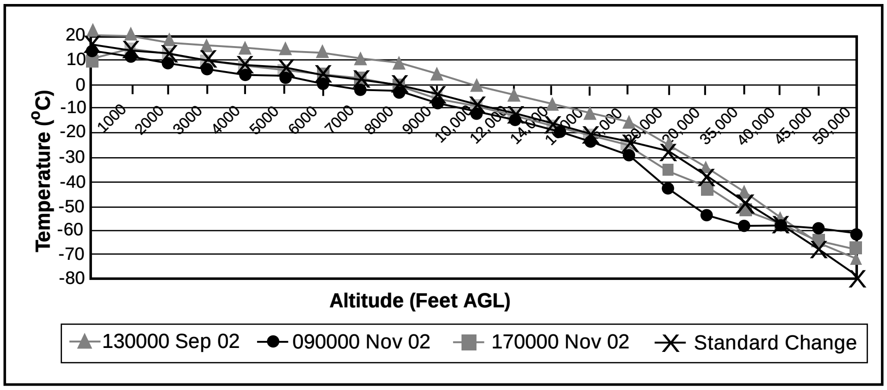

Figure 5: Temperature vs Altitude for Three Different Days

there. Therefore, we had to estimate the temperature at Cobra's Met station as compared to Shkin's surface temperature. To avoid simply guessing the temperature difference between the Met station and the firing point, we used Table D of the tabular firing table to help calculate it.

The drawback to Table D is that it only works for changes in altitudes less than 390 meters. So we extended the data mathematically and applied human logic for altitude changes greater than 390 meters.

Easy Access to IGRADS. Once the Army emplaced a SIPR line into the artillery tactical command post (TAC) at Forward Operating Base (FOB) Salerno, which was a few hundred meters from Firebase Cobra Strike, we could get Met data directly from IGRADS. Not only could we compute current Met messages for the firebase, but we also could produce Met messages for any Met station the mission dictated.

Before departing on a weeklong ground assault convoy that covered more than 400 kilometers southwest of Gardez during Phase III of Operation Alamo Sweep, we generated Met messages at two- to four-hour intervals over a 24-hour period for all three of the future firing points. (See Figure 4.) In this manner, the battery no longer had to estimate the temperature difference between a current firing point and the previous Met station or rely on a Met message that was calculated for a Met station much farther away than the advised distance of 10 kilometers.

We prepared the Met messages for the three new position areas by computing a day's average pressure at each zone for each firing point and then using that data for each of the 10 Met messages. We again created Met messages for five-degree temperature changes, this time ranging from 30 to 75 degrees Fahrenheit.

For Firebase Cobra Strike, Met data now could be forecast with IGRADS that fell within the distance and time requirements of FM 6-15. Based on a daily access to the SIPR net, we could account for winds after we converted the wind speeds to knots and wind directions to mils. When it was not feasible to obtain the Met data for the day, we did not account for wind and used the average pressure profile to generate Mets, as explained in Figure 4. Wind changes are often enough to prevent an FDC from using wind data that is even a few hours old.

Ballistic Mets. IGRADS output also can be converted to ballistic Met messages for mortars, a capability that has become more important to the artillery due to recent deployments of artillery batteries armed with 120-mm mortars.

However, a ballistic Met message is not as straightforward as a computer Met message. The air density and temperature values at each line of the Met message represent a weighted average of the conditions from the surface through that line of Met and back to the surface again and are listed as percentages of standard. The ballistic air density for Line 2 is, therefore, a weighted average of the air densities of Line 1 and Line 2.

To convert the Air Force Met data to a ballistic Met message, one must use the weighting factors and standard conditions found in FM 6-16. Figure 6 shows an example computation for ballistic air density for Line 2 of the Bagram Met. Ballistic temperatures are computed in a similar manner (consult FM 6-16, Pages 2-83, 2-104, 2-133).

Future Use of IGRADS. The Air Force's IGRADS has proven a powerful tool to support an artillery or mortar battery left without a supporting Met section. IGRADS allowed C/1-319 AFAR to fire accurately in a rugged climate despite the lack of normal artillery Met support. Range errors were small or nonexistent. We could also have decreased our deviation errors with more consistently available wind data.

The Field Artillery and Army should consider tapping into this system or implementing a similar system. To fully use the software's capability and free an FDC from relying on a spreadsheet or a calculator, we would have to alter the output of the software to match the format of computer and ballistic Met messages. When that happens, the Army will be better poised to rapidly react to small-scale warfare across the globe.

It is likely that another battery will find itself without artillery Met support somewhere in the world during future phases of the War on Terrorism, and it is in America's best interest to set it up for success.

First Lieutenant Joshua D. Mitchell is the Fire Direction Officer for C Battery, 1st Battalion, 319th Airborne Field Artillery Regiment, 82d Airborne Division, Fort Bragg, North Carolina, currently deployed to Afghanistan for Operation Enduring Freedom. In his previous assignment with the 82d Division Artillery, he was the Fire Support Officer for B Company, 2d Battalion, 505th Parachute Infantry Regiment. He holds Bachelor's Degrees in Biomedical Engineering and Mathematical Sciences from Johns Hopkins University. He was a Distinguished Graduate of his Field Artillery Officer Basic Course and the recipient of the Gunnery Award (FAOBC 06-2000) at Fort Sill, Oklahoma.

	Line 1	Line 2	
Standard Air Density (gm/m^3)	1213.3	1184.4	1. 1213.3 x 0.43 + 1184.4 x 0.57 = 1,196.8 gm/m^3 (Standard Ballistic Air Density for Line 2)
Bagram Air Density (gm/m^3)	985.8	977.6	2. 985.8 x 0.43 + 977.6 x 0.57 = 981.1 gm/m^3 (Bagram Ballistic Air Density for Line 2)
Weighting Factors for Line 2	0.43	0.57	3. 981.1/1,196.8 = 82.0% (Bagram Air Density for Line 2 Expressed as Percent of Standard)

Figure 6: Procedures for Computing Ballistic Air Density